Measurements of strange and non-strange charm production in PbPb collisions at 5.02 TeV with the CMS detector

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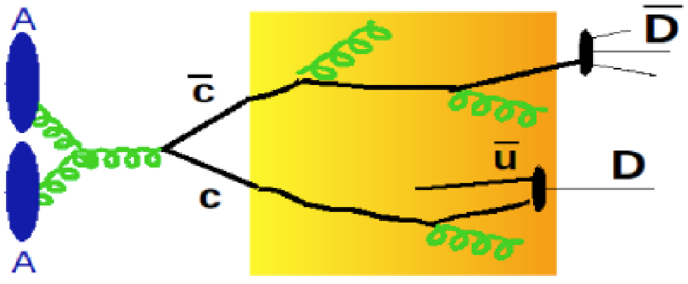
for the CMS Collaboration

Strangeness in Quark Matter 2019

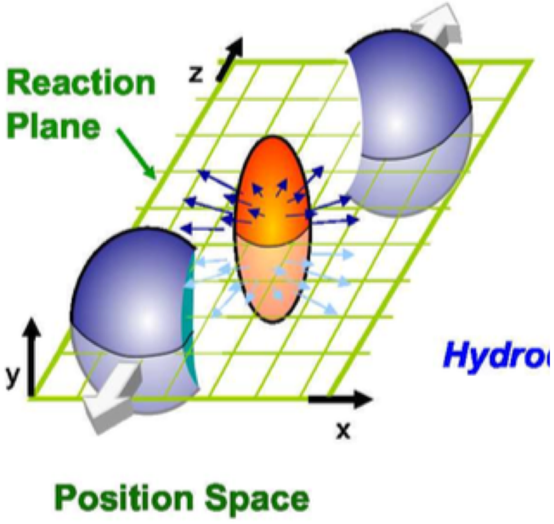
Motivation

- Heavy quarks produced early , experience the full evolution of the medium



- D^0 R_{AA}: nuclear modification factor
  - Flavor dependent energy loss
  - Dead cone effect (Phys. Lett. B **519** (2001) 199)

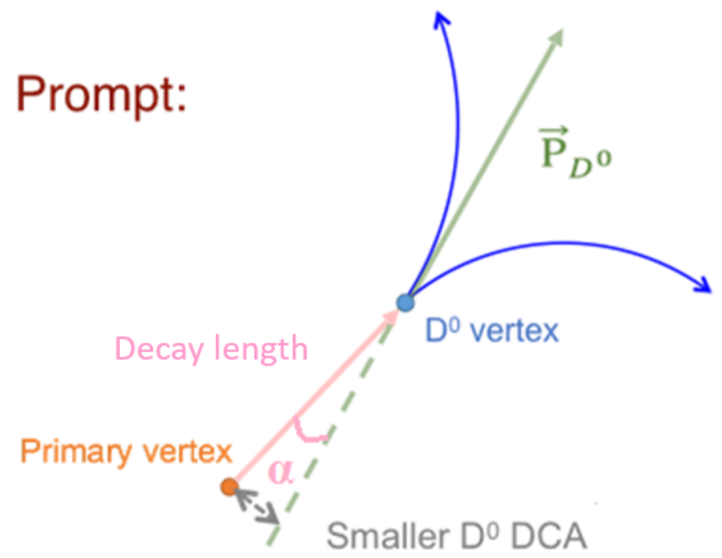
- D^0 v_n harmonics in PbPb :
  - At low p_T , the degree of medium thermalization
  - At high p_T, the path length dependence of energy loss



- D^0 elliptic flow v_2 in high multiplicity pPb
  - Evidence of QGP in small system?
  - Heavy flavor hydrodynamic flow?

D Meson Reconstruction & Selection

- $D^0 \rightarrow K^-\pi^+$, BR = 3.89% , $c\tau \simeq$120 μm
- D^0 candidates :
  - pairing two charged tracks
  - kinematic fitter



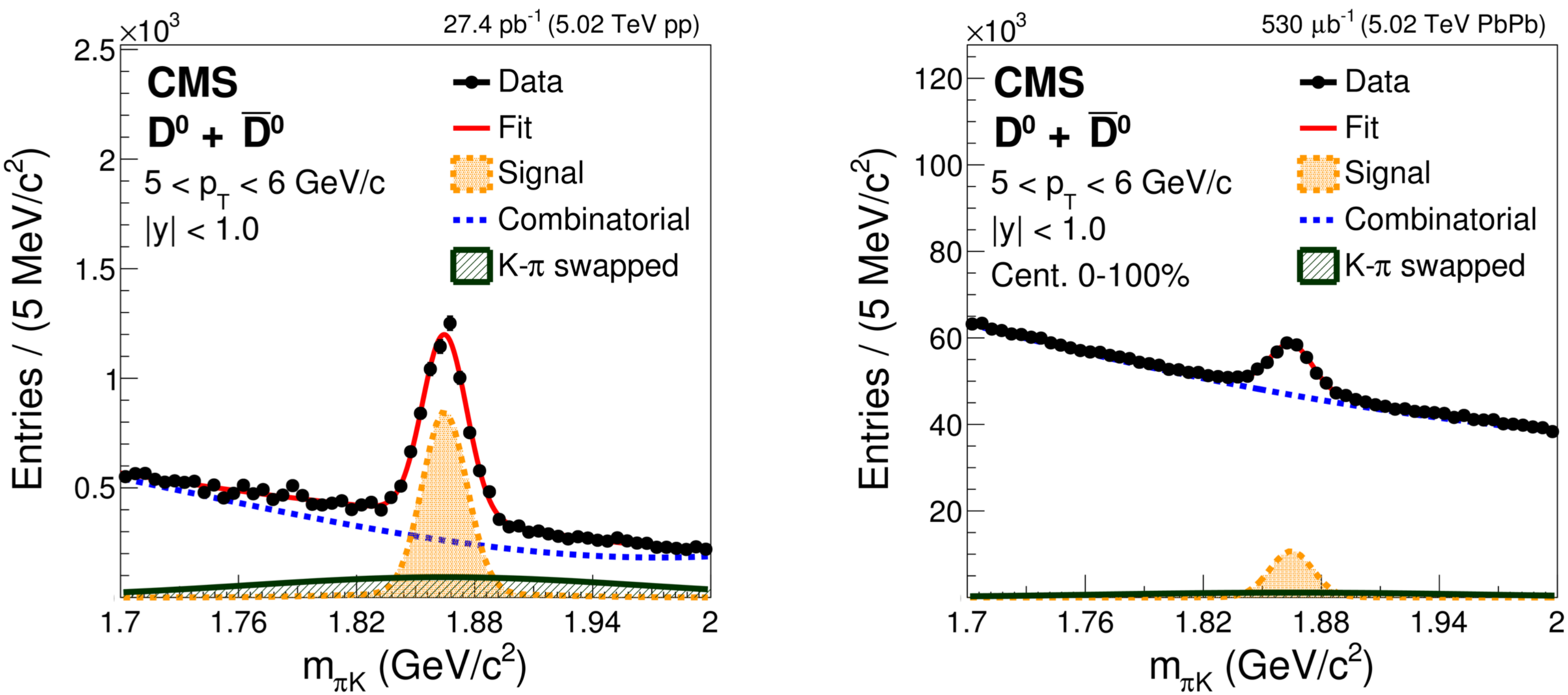
- D^0 candidates selection (Rectangular Cuts optimized using TMVA)
  - Pointing angle α < 0.12 – 0.15
  - 3D decay length significance > 3.0 – 4.8
  - D^0 candidate vertex probability > 0.05 – 0.25
  - Distance of Closet Approach (DCA) < 0.008 cm (in v_n analysis)

D^0 Signal Extraction by Invariant Mass Fit

D^0 invariant mass distributions are fitted by

- Double Gaussian (Signal)
- 3rd order polynomial (Combinatorial)
- Single Gaussian (K-π swapped. No PID. Candidates with wrong mass assignment on tracks)

PLB **782**,474(2018)



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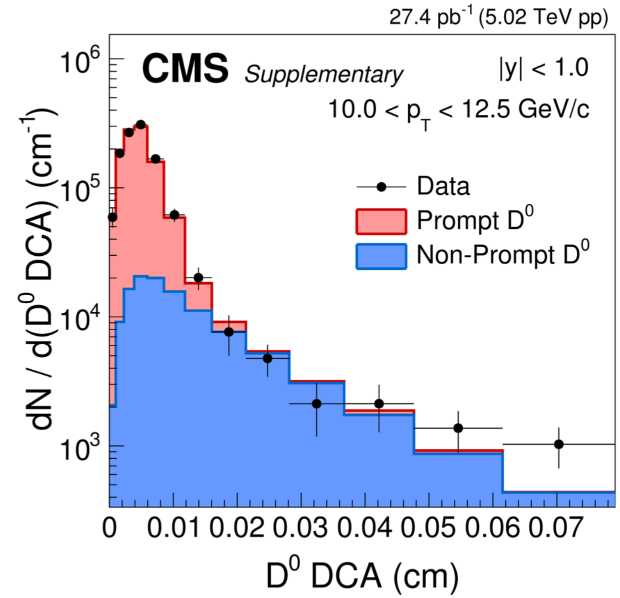
Extract Prompt Fraction from Data

- D^0 in data is a mixture of prompt and non-prompt D^0

- Fit DCA of data with prompt and non-prompt D^0 DCA MC templates



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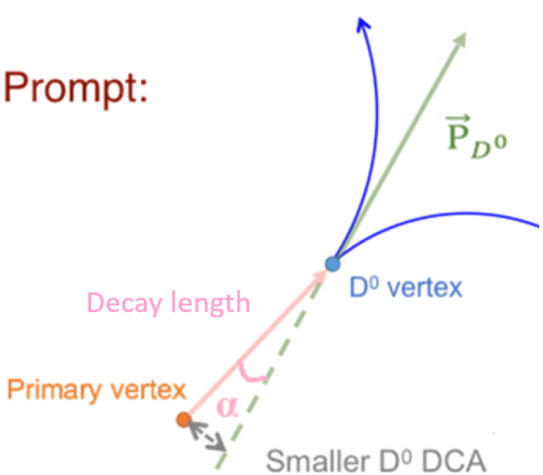
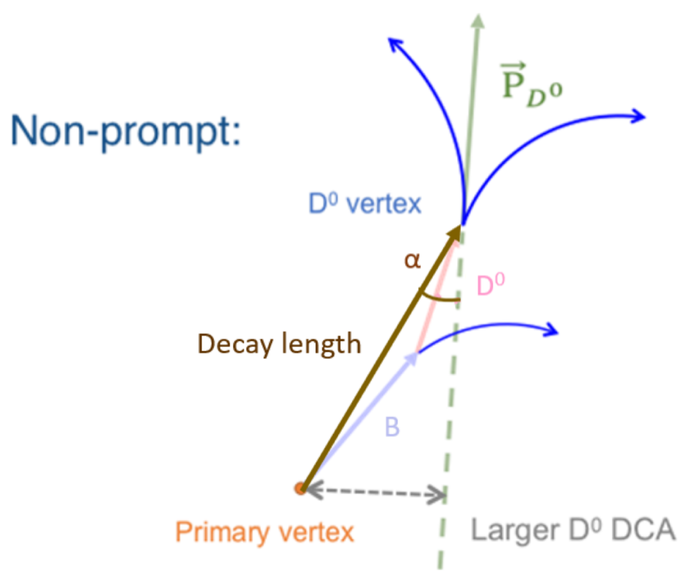
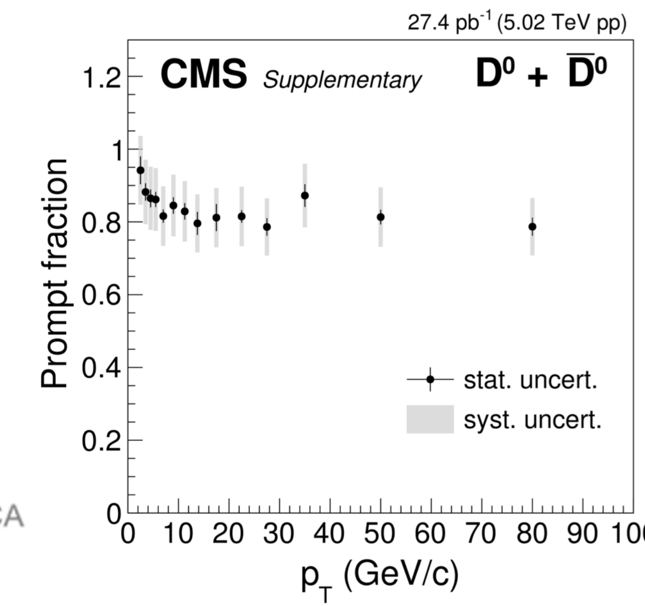
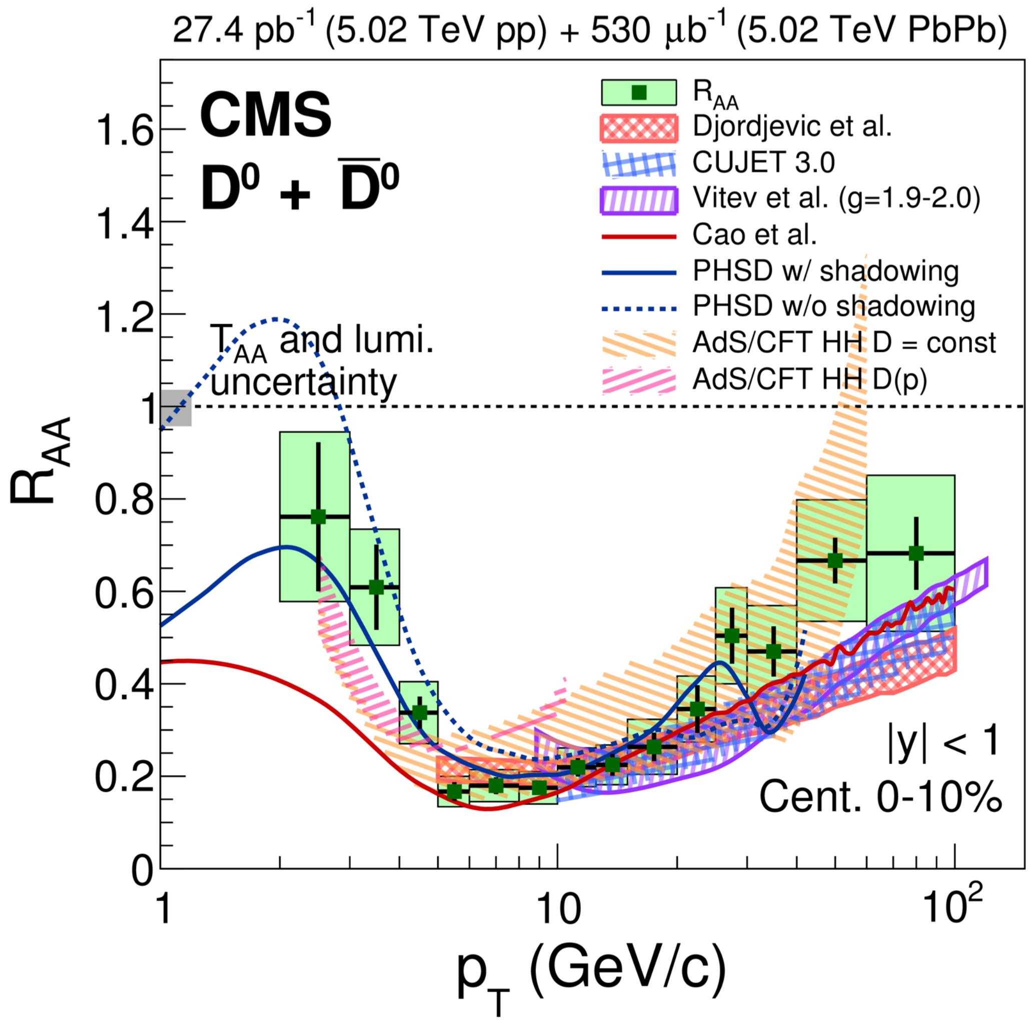






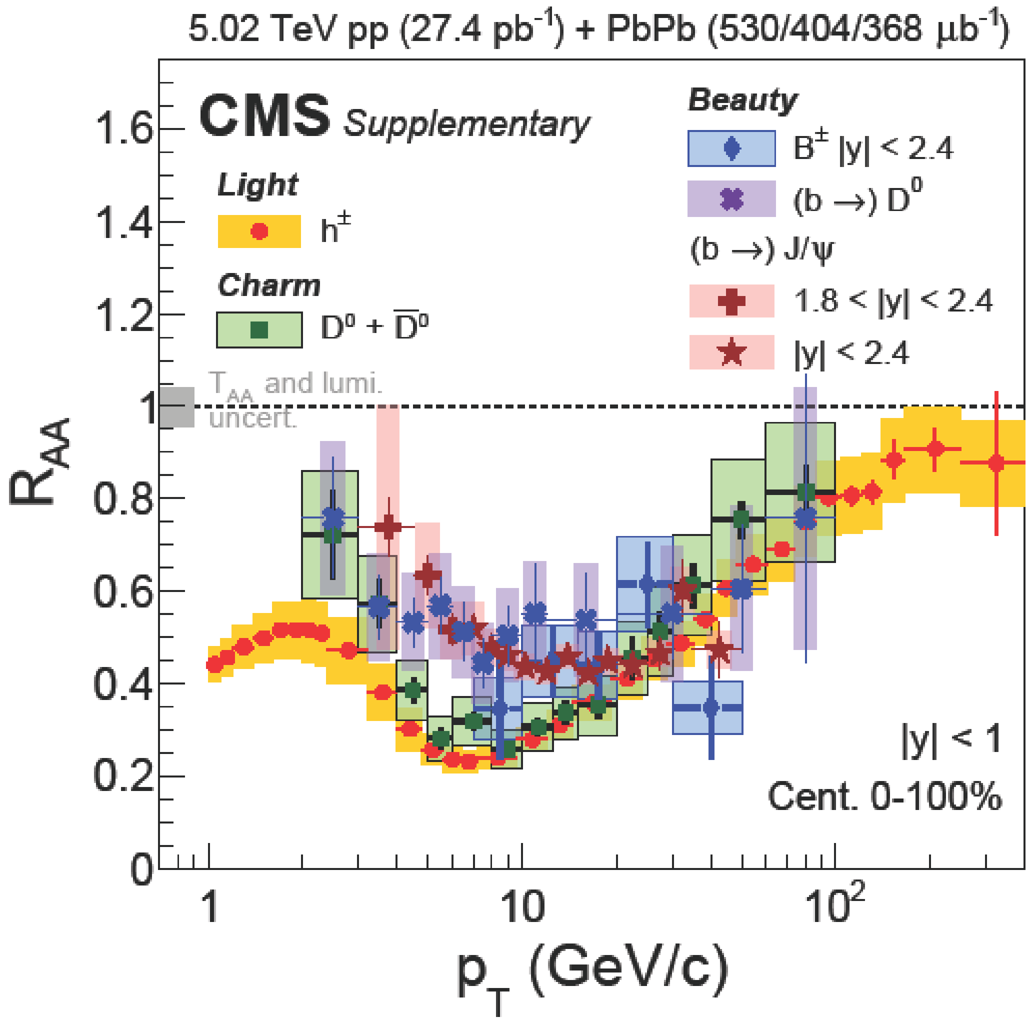
D^0 R_{AA} and Comparison with Model Calculations



- Charm quarks lose a significant fraction of energy in the QGP medium
- R_{AA} minimal near $p_T \sim 10$ GeV/c and then increases
- At high p_T, both pQCD and AdS/CFT predictions reasonably agree with R_{AA} results
- At low p_T, PHSD with shadowing describes data better

PLB **782**,474(2018)

R_{AA} Zoo Plot and Comparison



- At low p_T, a hint of smaller suppression of D^0 and non-prompt J/ψ than charged particles
- At high p_T, the D^0 R_{AA} is similar to charged particles R_{AA}
- The non-prompt J/ψ appear to be less suppressed than the D for p_T smaller than ~15 GeV

JHEP **04**(2017)39

PRL **119**,152301(2017)

PLB **782**,474(2018)

EPJC **78** (2018) 509

D^0 v_n in PbPb collisions at 5.02 TeV

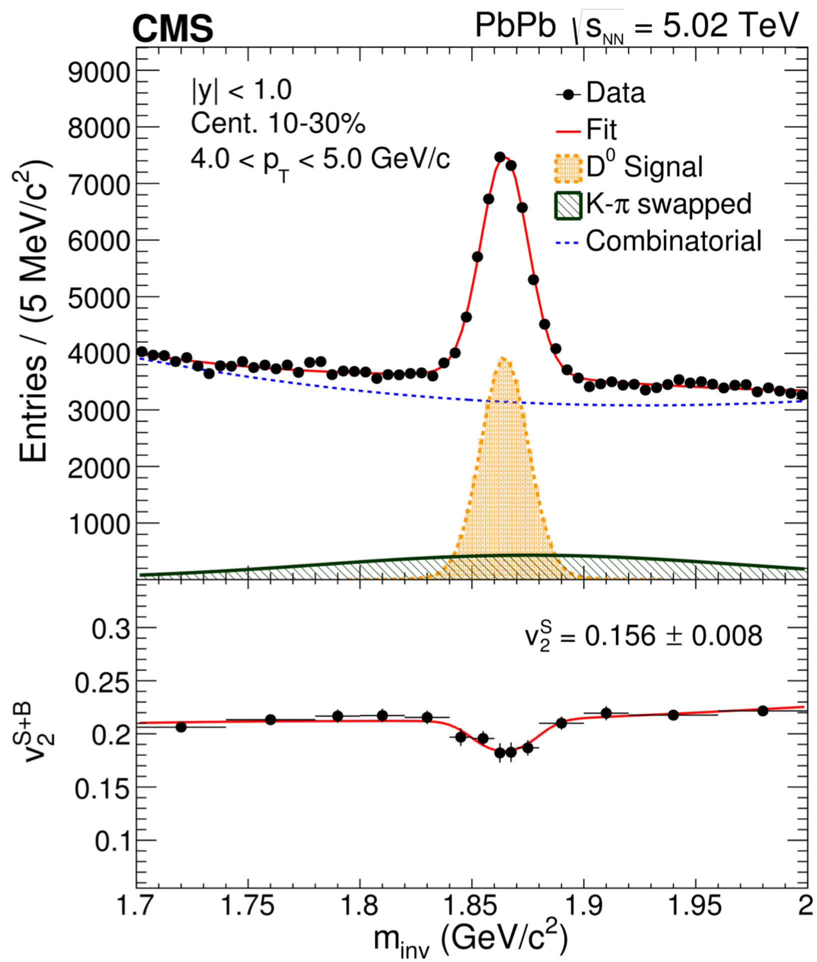
- v_n obtained by scalar product method

(Luzum, Ollitrault PRC **87** (2013), 044907)

- Simultaneous fit on mass distribution and v_n vs. mass

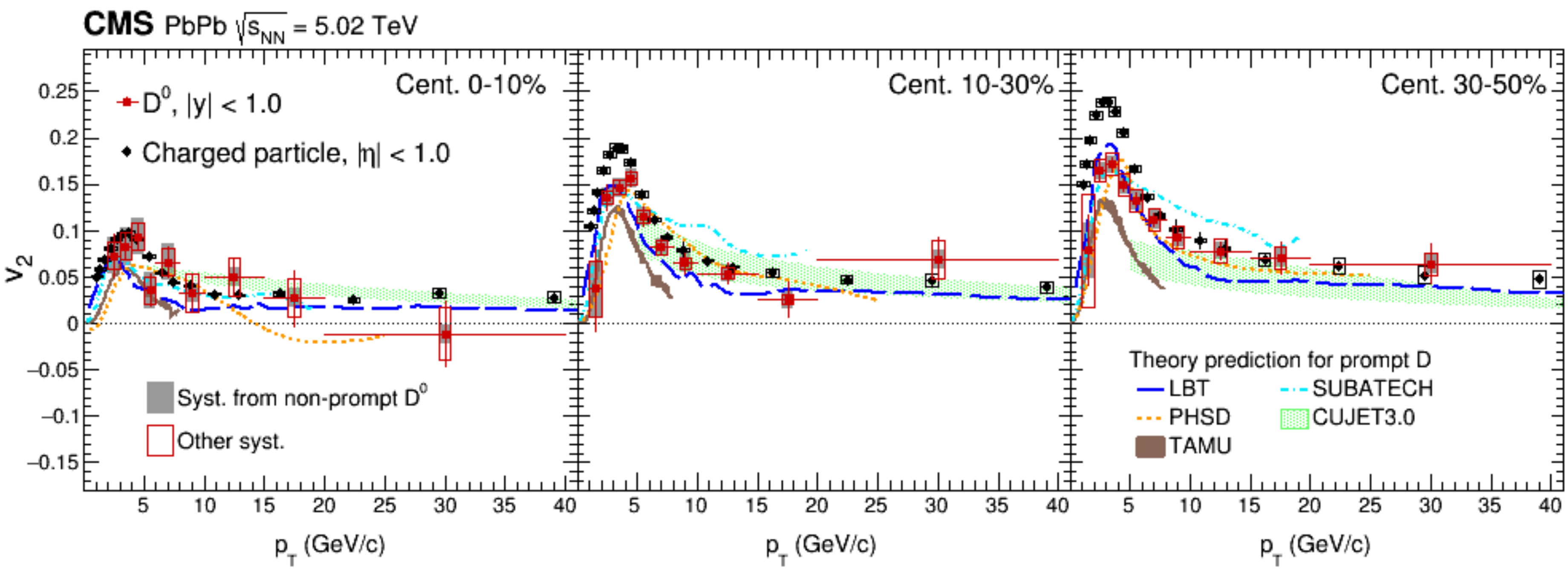
$$v_n^{S+B}(m) = \alpha(m) v_n^S(m) + [1 - \alpha(m)] v_n^B(m)$$

$$\alpha(\mathrm{m}) = \frac{\mathrm{Sig}(m) + \mathrm{Swap(m)}}{\mathrm{Sig}(m) + \mathrm{Swap}(m) + \mathrm{Bkgd(m)}}$$



PRL **120**,202301(2018)

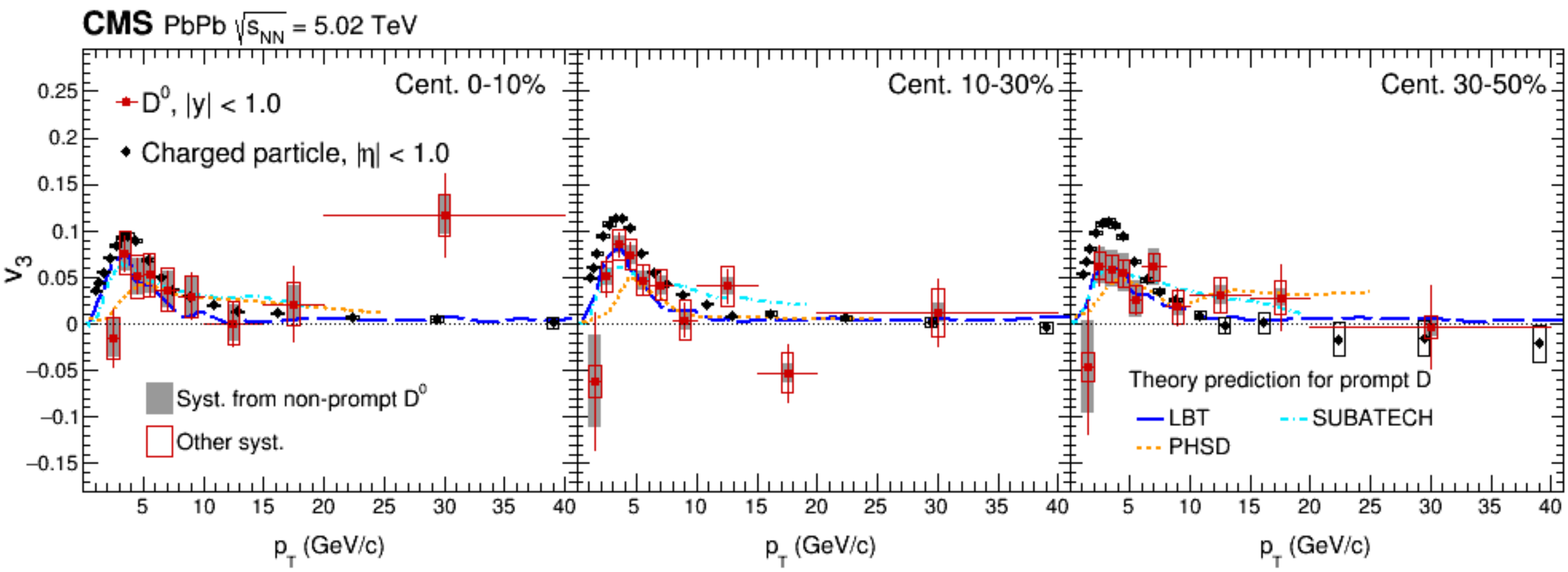
Prompt D^0 v_2 Result



PRL **120**,202301(2018)

- Positive prompt D^0 v_2 is observed:
  - Low p_T : charm quark collective motion
  - High p_T : path length dependence of energy loss
- Similar p_T dependence to charged particle
- At centrality 10-30% and 30-50% , the $v_2(D^0) < v_2$(charged particle)
  - Mass ordering or other effect?

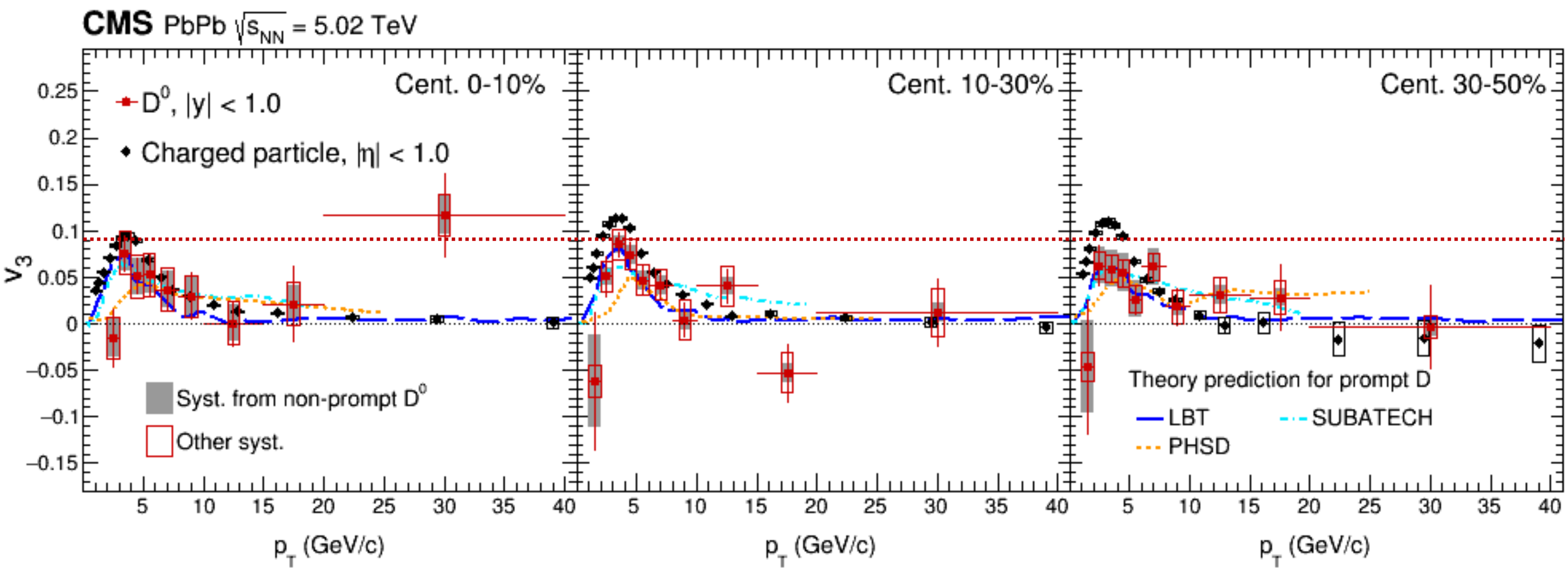
Prompt D^0 v_3 Result



- Low p_T : v_3(prompt D^0) >0 ; Hight p_T : v_3(prompt D^0)≈0
- Similar p_T dependence to charged particle

PRL **120**,202301(2018)

Prompt D^0 v_3 Result



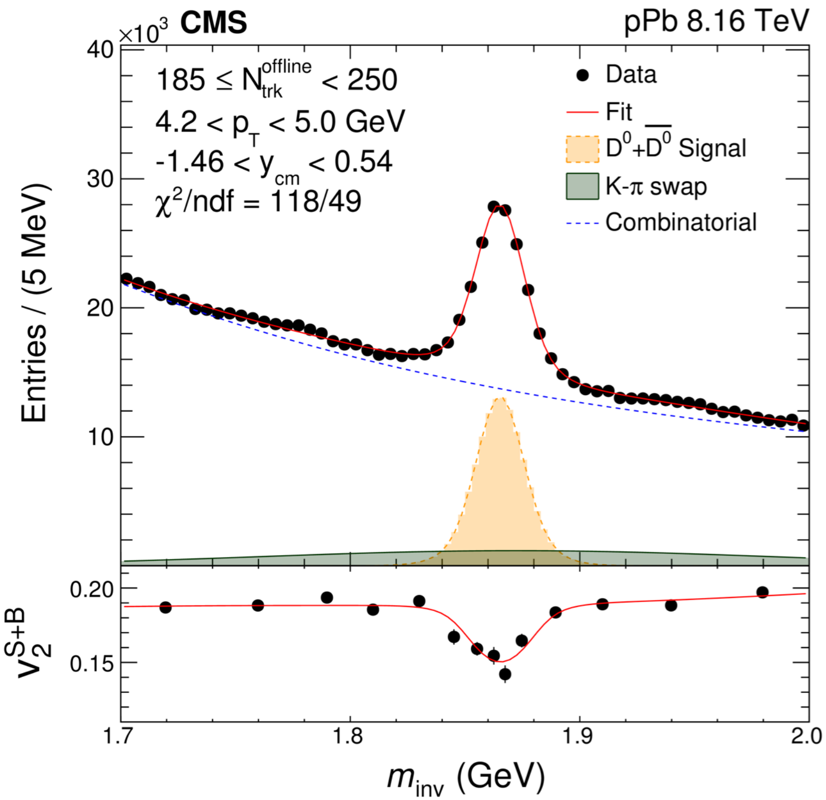
- Low p_T : v_3(prompt D^0) >0 ; Hight p_T : v_3(prompt D^0)≈0
- Similar p_T dependence to charged particle
- Little centrality dependence
  - Indicate a constant initial geometry
- v_2 and v_3 results provide constrain on models

PRL **120**,202301(2018)

D^0 v_2 in pPb Collisions at 8.16 TeV

- Two-particle correlation method

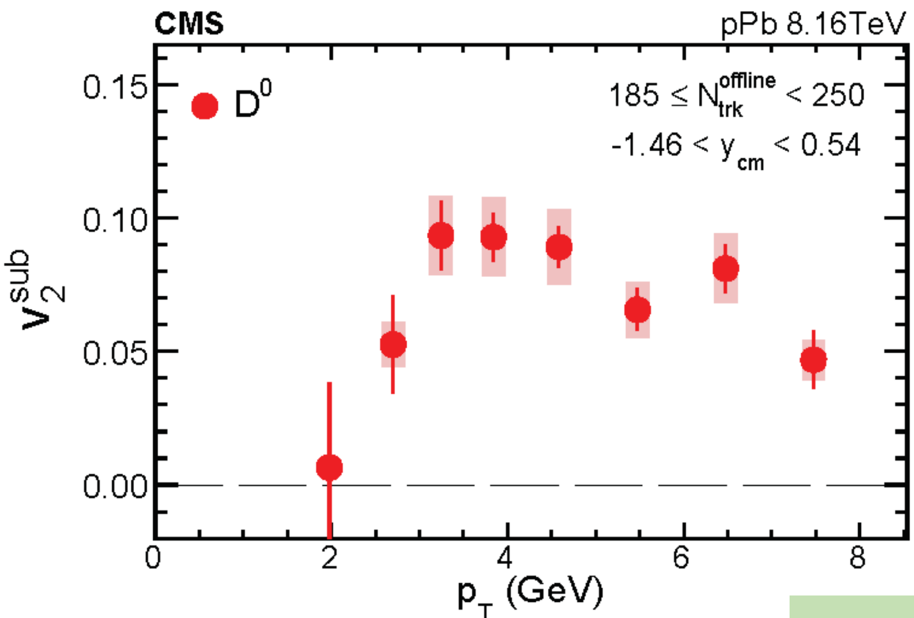
  to extract v_2
  - Correlate D^0 and charged hadrons ($|\Delta\eta|$gap = 1)
  - Perform Fourier fits the two particle correlation
  - $v_2^{D^0}(p_T) = \frac{V_{2\Delta}(p_T^{D^0}, p_T^{assoc})}{\sqrt{V_{2\Delta}(p_T^{assoc}, p_T^{assoc})}}$

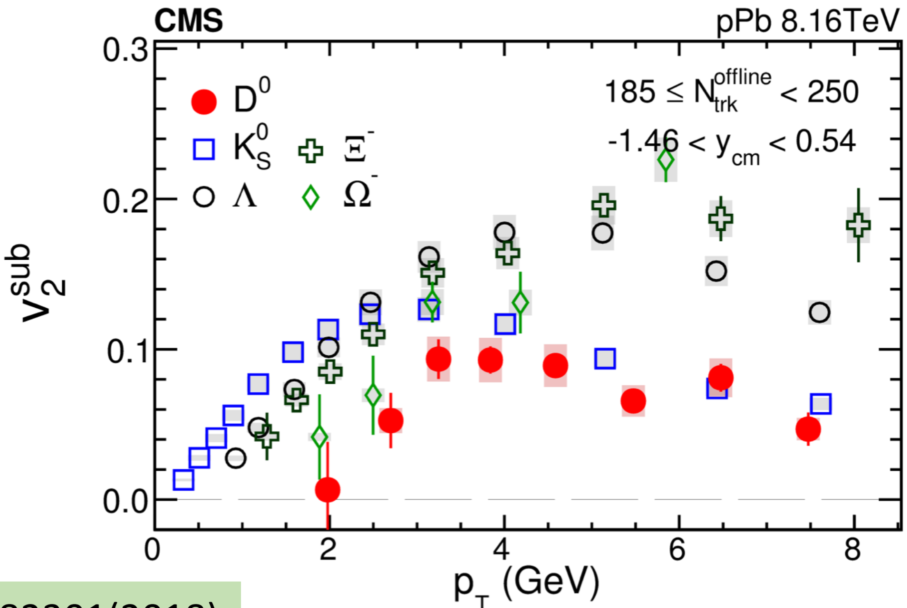


PRL **121**,082301(2018)

- D^0 v_2^{sub} , to reduce the non-flow contributions
  - subtracting the $V_{2\Delta}$ in low multiplicity (Ntrk <35)
- Simultaneous fit on mass distribution and v_2 vs. mass

D^0 Meson and Strange Hadrons v_2 vs p_T

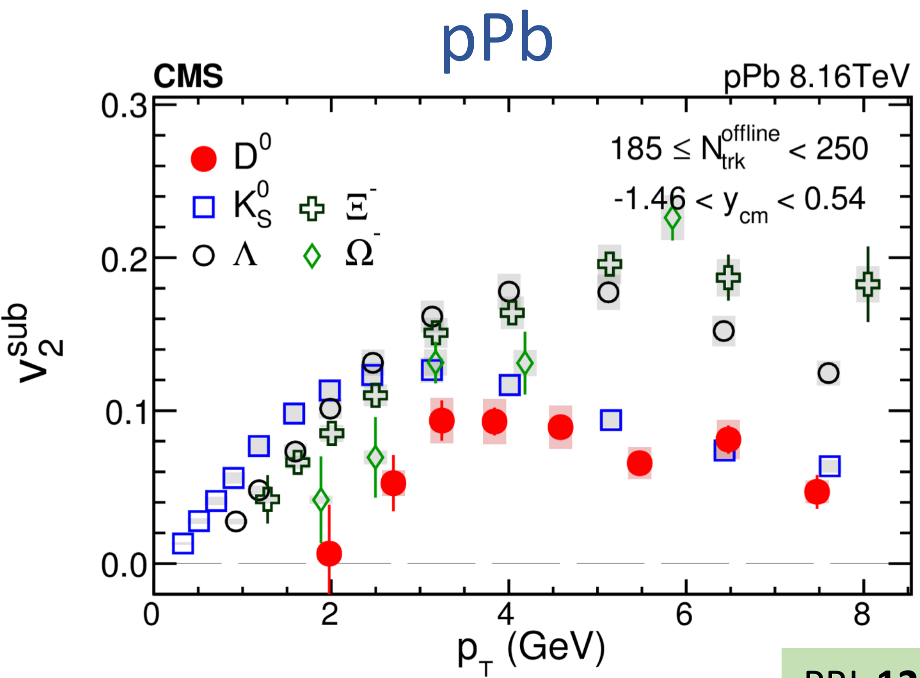


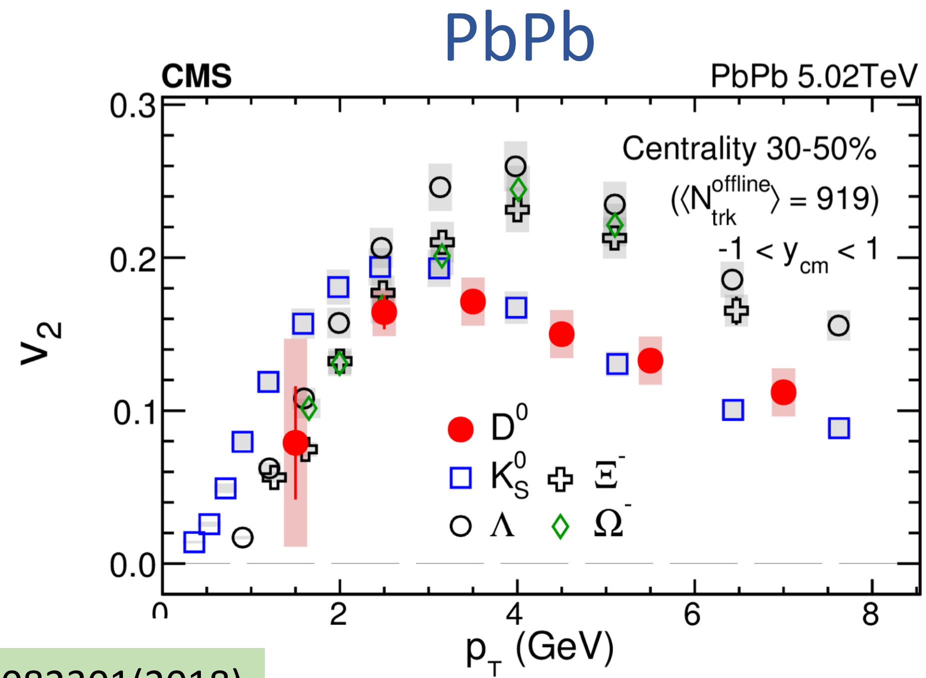


PRL **121**,082301(2018)

- Significant D^0 v_2 have been observed in high multiplicity pPb
- $v_2^{D^0} < v_2^{strange\ hadrons}$

D^0 Meson v_2 vs p_T and PbPb Collisions



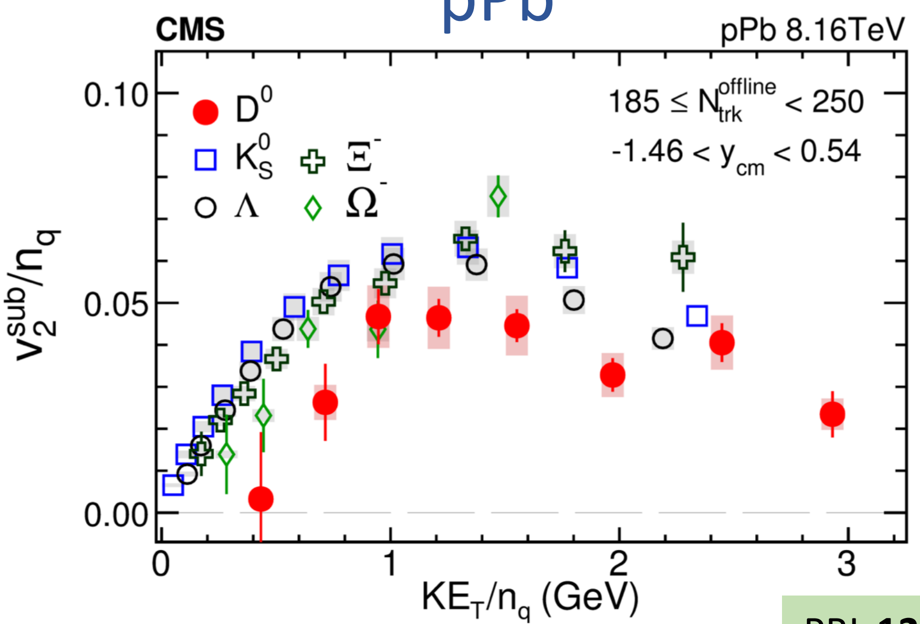


PRL **121**,082301(2018)

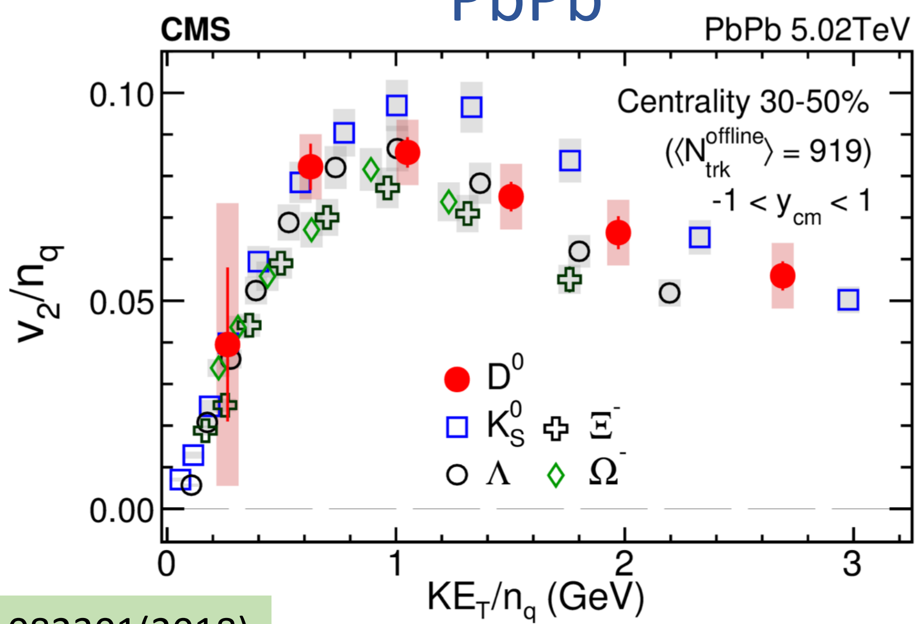
- $D^0\ v_2^{pPb} < v_2^{PbPb}$ for a given p_T
- Similar mass ordering for pPb and PbPb

D^0 NCQ Scaling v_2 in pPb and PbPb

pPb



PbPb

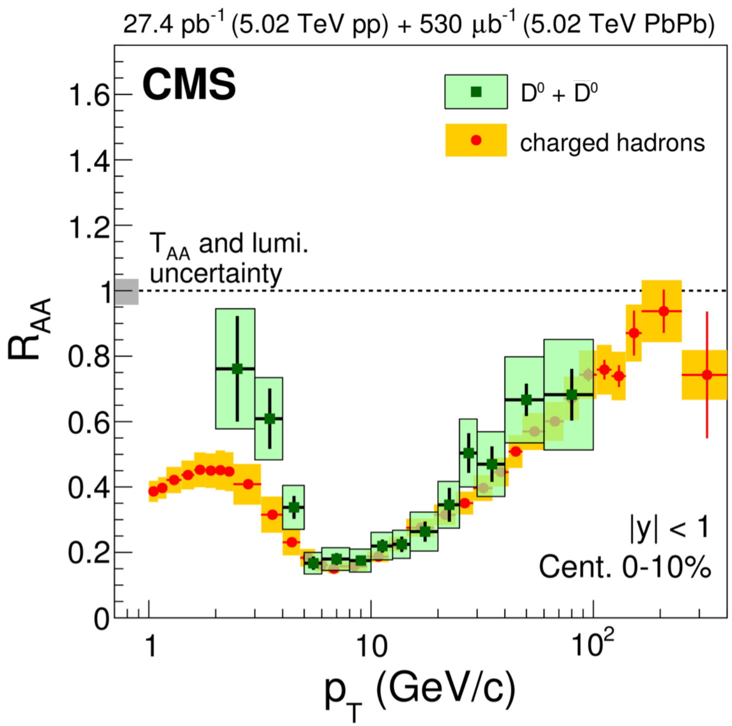


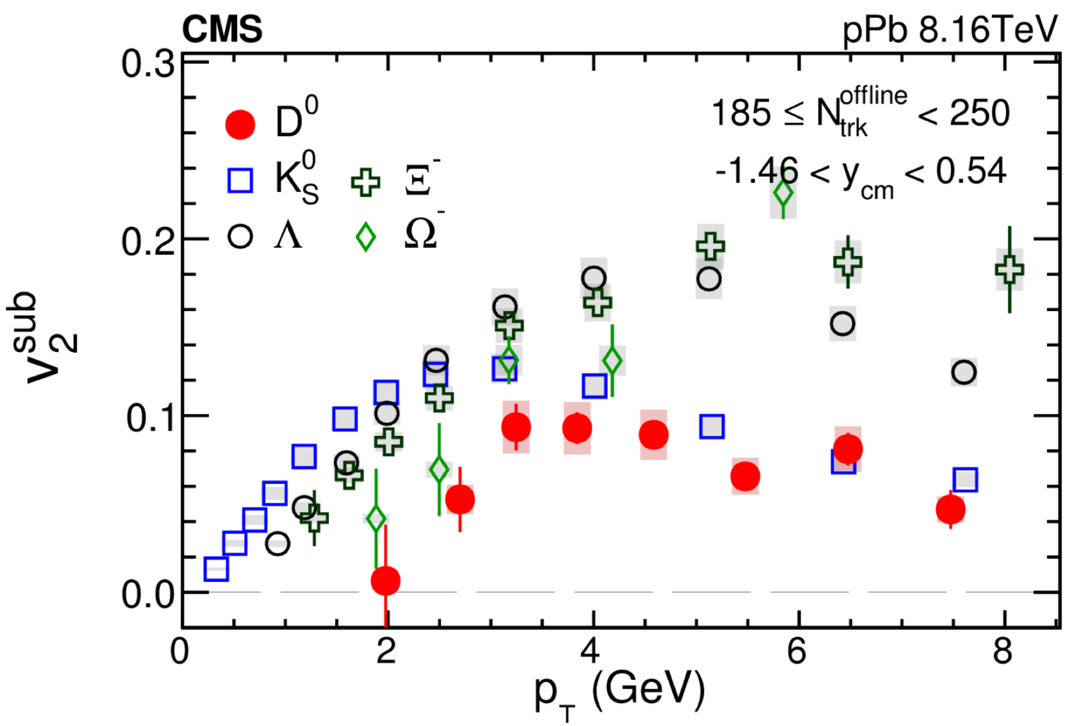
PRL **121**,082301(2018)

- Number of constituent quarks (NCQ) scaling is motivated by quark coalescence model
- In pPb, D^0 v_2/n_q is smaller than strange hadrons for KE_T/n_q <2
- In PbPb, D^0 v_2/n_q follow the same trend as other particle species

Summary

- D^0 R_{AA} **at 5.02 TeV PbPb**
  - Strong suppression of D^0 R_{AA}
  - $R_{AA}(D^0) \sim R_{AA}(h^{\pm})$ at high p_T
  - $R_{AA}(D^0) > R_{AA}(h^{\pm})$ at low p_T
- D^0 v_2 **at 8.16 TeV pPb**
  - Significant v_2 in high multiplicity events
  - $v_2(D^0) < v_2$ (strange hadrons)





Back Up

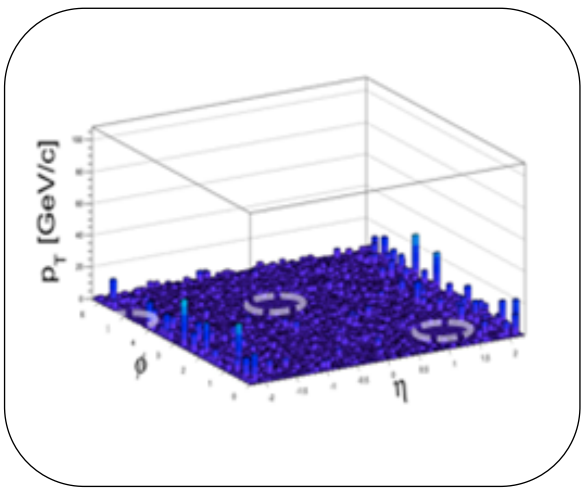
The CMS Trigger and Data Sets

Data sets

- LHC Run II 2015 pp and PbPb **at** $\sqrt{s_{NN}}$ **= 5.02 TeV** and 2016 pPb data **at** $\sqrt{s_{NN}}$ **= 8.16 TeV**
- Minimum bias sample for $p_T < 20$ GeV/c and triggered samples for $p_T > 20$ GeV/c
- Dedicated HLT D meson filters to enhance the statistics of very high p_T D mesons
- High multiplicity trigger to select high **multiplicity pPb** events comparable to peripheral PbPb

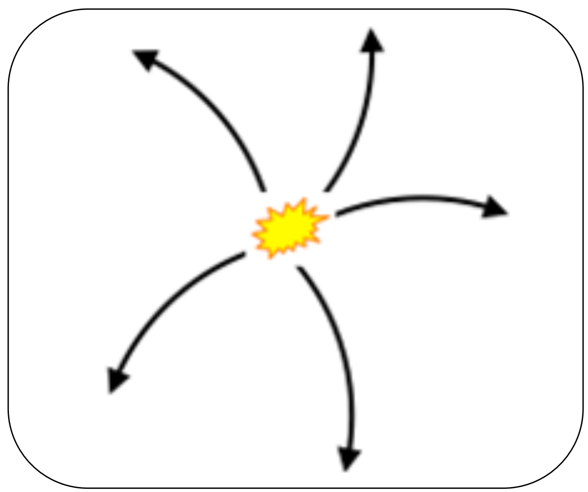
Triggering system

Hardware Level 1
Jet Trigger Selections



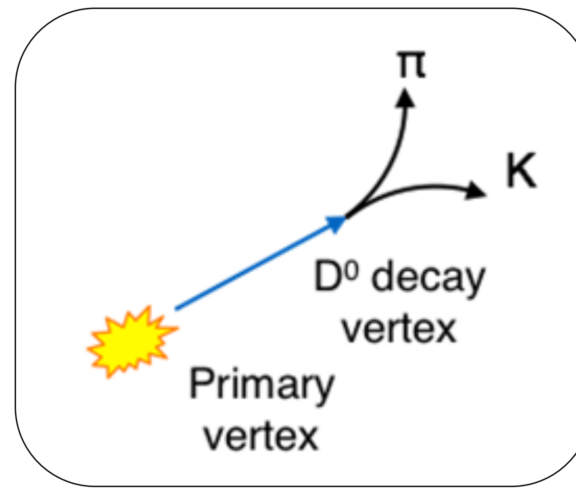
Level 1 (L1) jet algorithm with online background subtraction

Track Selections
in Software Triggers



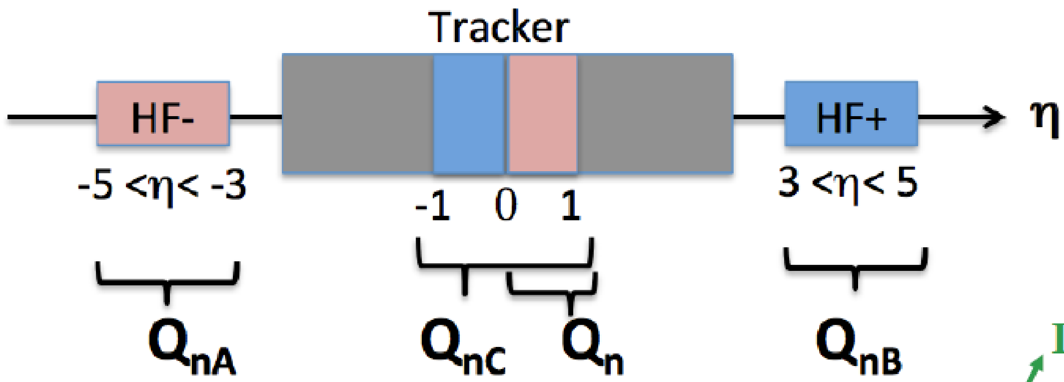
Track seed p_T cut applied:
$p_T > 2$ GeV/c for pp/pPb
$p_T > 8$ GeV/c for PbPb

$\boldsymbol{D^0}$ **Selections**



D^0 online reconstruction
Loose selections based on D^0 vertex displacement

Scalar Product Method



$$Q_n = \sum_j w_j e^{in\phi_j}$$

Sum over tracks (tracker), or towers (HF)
***w_j*: tower E_T for HF, track p_T for tracker**

D[0] candidate

$$v_n\{SP\} = \frac{\langle Q_n \cdot Q_{nA}^* \rangle}{\sqrt{\frac{\langle Q_{nA} \cdot Q_{nB}^* \rangle \langle Q_{nA} \cdot Q_{nC}^* \rangle}{\langle Q_{nB} \cdot Q_{nC}^* \rangle}}}$$

Scaling factor from 3 sub events

- Large η gap applied ($|\Delta\eta|>3.0$)
- $v_n\{SP\}$, non-ambiguous measure of $\sqrt{\langle v_n^2 \rangle}$

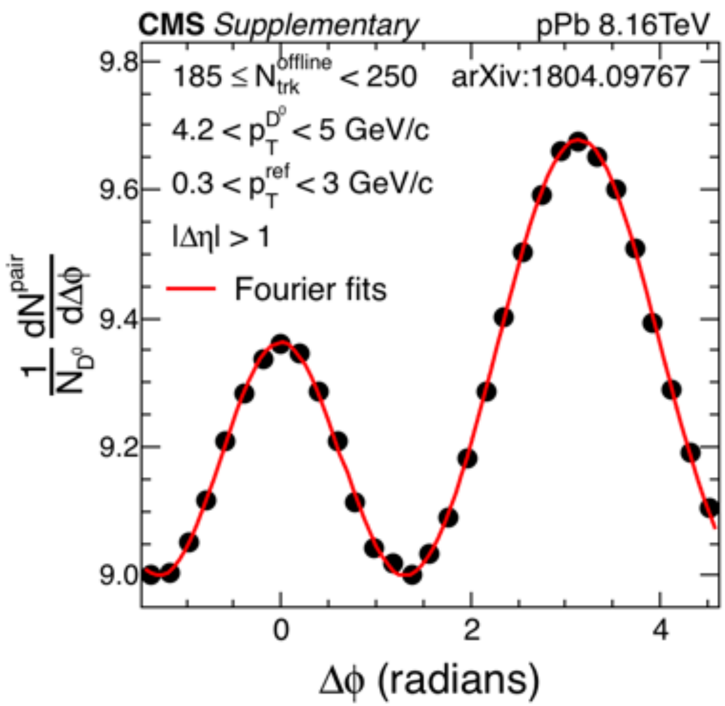
Luzum, Ollitrault PRC **87** (2013), 044907

D^0 v2 in pPb Collisions at 8.16 TeV

- **Fourier series describing the azimuthal anisotropy of particle spectrum**

$$\frac{dN}{d\phi} \propto 1 + \sum 2v_n(p_T,\eta)cos[n(\phi-\psi_n)]$$

- **Two-particle correlation method to extract v_2**
  - Correlate D^0 and charged hadrons ($\Delta\eta$ gap = 1)
  - Perform Fourier fits the two particle correlation



distribution for D^0 to extract $V_{2\Delta}(p_T^{D^0}, p_T^{assoc})$

- $D^0\ v_2(p_T)$ can be obtain by :

$$v_2^{D^0}(p_T) = \frac{V_{2\Delta}(p_T^{D^0}, p_T^{assoc})}{\sqrt{V_{2\Delta}(p_T^{assoc}, p_T^{assoc})}}$$

CMS HIN-17-003
Phys. Rev. Lett **121**,082301(2018)